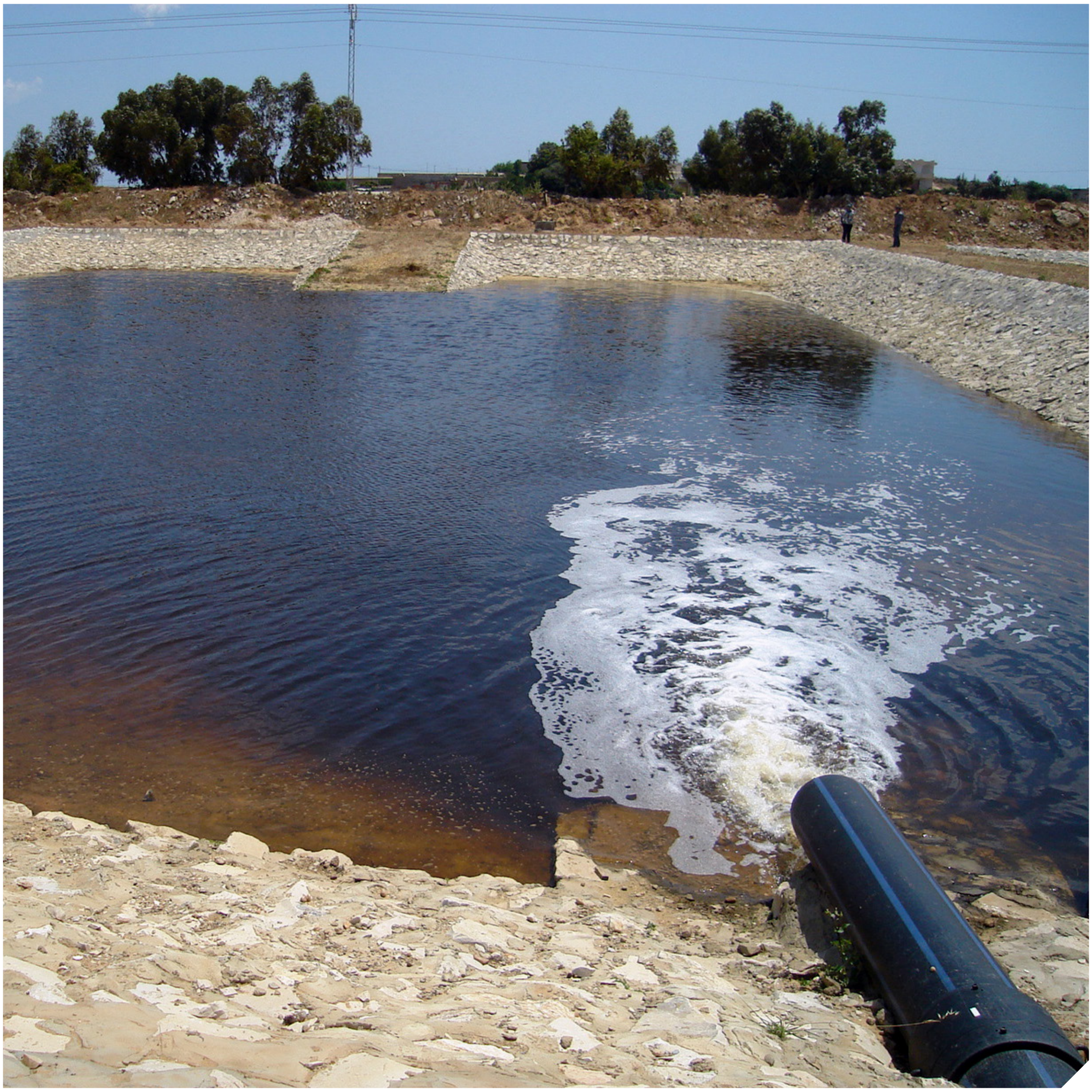
THE NEXUS APPROACH AND SAFE USE OF WASTEWATER IN AGRICULTURE: AN INTERNATIONAL WORKSHOP ON POLICY AND IMPLEMENTATION FOR TUNISIA

PROCEEDINGS

Tunis, Tunisia, 12–14 December 2017



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Institute for Integrated Management of Material Fluxes and of Resources

Proceedings

The Nexus Approach and Safe Use of Wastewater in Agriculture: An International Workshop on Policy and Implementation for Tunisia

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(UNU-FLORES)

12–14 December 2017
Tunis, Tunisia

Co-Organised By:
United Nations University Institute for Integrated Management of Material Fluxes and of Resources (UNU-FLORES) (Dresden, Germany)
National Research Institute for Rural Engineering, Water, and Forestry (INRGREF) (Tunis, Tunisia)
Technical University of Denmark (Lyngby, Denmark)
Institution of Agricultural Research and Higher Education (IRESA)

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Photo Credit: Rachel Ahrens (sessions), Serena Caucci (field)
Print: Reprogress GmbH
Print run: 300

ISBN: 978-3-944863-72-6
e-ISBN: 978-3-944863-73-3

This publication should be cited as:
Caucci, Serena and Hiroshan Hettiarachchi. 2018. *The Nexus Approach and Safe Use of Wastewater in Agriculture: A Workshop on Policy and Implementation for Tunisia. Proceedings, Tunis, 12–14 December 2017*. Dresden: United Nations University Institute for Integrated Management of Material Fluxes and of Resources (UNU-FLORES).

Background

The term *nexus* was introduced to environmental resources management in the 1980s for the first time. The resource management disciplines continued to use the nexus concept to explain the interdependencies between different resources worldwide. Examples of these nexuses included water-electricity, water-energy, groundwater-electricity, water-agriculture, and finally, water-energy-food (WEF). The WEF Nexus especially postulates that a Nexus Approach would result in improved water, energy, and food security by integrating management and governance across sectors and scales. It is also implicit that a nexus application would reduce trade-offs, build synergies, promote sustainability, and thus pave the way as we transit to a green economy. In 2012 UNU-FLORES was established to look into the material resources perspective of the Nexus Approach, and in particular, to promote integrated management of water, soil, and waste in a nexus setting.

Wastewater irrigation provides an excellent practical example of the Water-Soil-Waste Nexus. On a global scale, over 20 million hectares of agricultural land are irrigated using wastewater. Water scarcity and the cost of energy and fertilisers are perhaps among the main factors driving farmers and other entrepreneurs to make use of wastewater. However, environmental, sanitary, and nutrition issues have emerged after its application in large-scale. To address the technical, institutional, and policy challenges for safe water reuse, developing countries and countries in transition need clear institutional arrangements and a deep understanding of opportunities and potential risks that the use of wastewater might bring with it. The Safe Use of Wastewater in Agriculture (SUWA) initiative currently led by UNU-FLORES is intended to address these needs. In recent years, UNU-FLORES has established working relationships in SUWA hotspots, such as, South America and Asia and is now looking at new challenges in the Middle Eastern and North African (MENA) region.

Through carefully designed wastewater irrigation schemes, Tunisia has played a pivotal role in the MENA region in promoting SUWA. Within this context, UNU-FLORES gladly accepted the invitation extended by the National Research Institute for Rural Engineering, Water, and Forestry (INRGREF) of Tunisia to co-organise a workshop on “The Nexus Approach and Safe Use of Wastewater in Agriculture”. Bringing different viewpoints together on to one platform is crucial in this exercise, and therefore knowledge has been presented by both international and local experts. Both UNU-FLORES and INRGREF used this opportunity to lay the foundation for a long-lasting and mutually beneficial partnership.

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Section 1: Setting the Scene

1.1 Introduction

As a solution to water scarcity and exponential groundwater abstraction, the use of reclaimed water for agricultural irrigation has been practised in arid and semi-arid countries for years, with different success rates. Water scarcity and cost factors drive millions of farmers and other entrepreneurs to make use of wastewater. Globally, over 20 million hectares of agricultural land are irrigated this way. However, much of this practice remains unregulated and its safety uncertain. Indeed, despite the direct and tangible benefits, health concerns around this practice are growing because the reuse of often untreated or poorly treated wastewater is the cause of health problems and continuous environmental pollution. Agricultural and water policies have not sufficiently addressed the inherent threats posed by the unsustainable use of wastewater for irrigation and aquifer replenishment. As a consequence, the hazardous materials in the form of heavy metals, organic contaminants, and pathogens might accumulate in soils, crops, and groundwater and thus, into the food chain.

In Tunisia, wastewater irrigation presents farmers with an excellent case for alternative water provisioning in times of limited freshwater resources. Experts are also starting to discuss whether wastewater may be an untapped resource for the replenishment of coastal aquifers, which are currently facing heavy salt intrusion.

The potential of the safe use of wastewater in agriculture (SUWA) has been heavily discussed – but upon large-scale application, environmental, sanitary, and food production issues have emerged worldwide. In Tunisia, this is no exception.

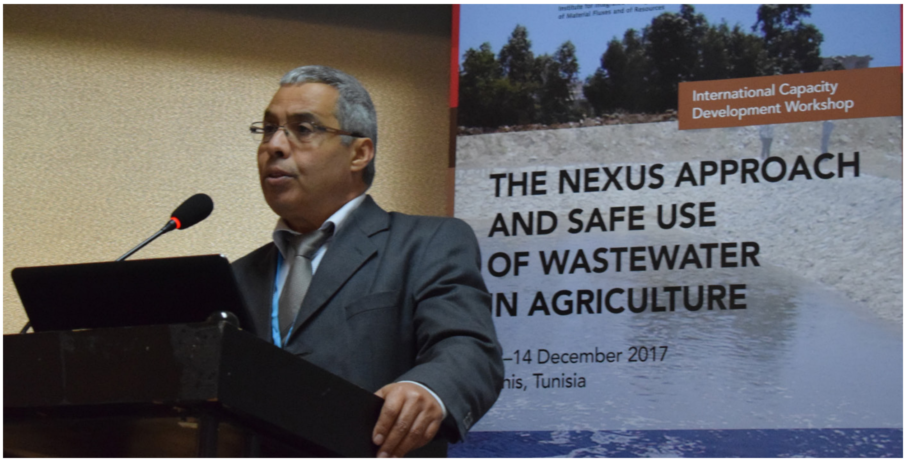
To ensure the safety of the population, laws and practices should ideally be pushing to reduce the problems related to unsafe wastewater use. As this is unlikely, because reality is not so straightforward, novel approaches capable of considering better management of natural resources should be developed.

The planned development of a standardised monitoring campaign to evaluate water quality and the benefits of an integrated approach for the management of natural resources will be of help for governments and local communities, which could capitalise on social pressure to force the stakeholders involved to think about the "safe use" of wastewater and long-term goal investments.

1.2 Workshop Overview

In the opening session of the workshop, the **Director General of INRGREF, Prof. Zouhaier Nasr** and **Director General of IRESA, Prof. Hichem Ben Salem**, gave the welcome remarks. On the first day, **Prof. Hiroshan Hettiarachchi (UNU-FLORES)** illustrated the capacity development aspects of the Safe Use of Wastewater in Agriculture (SUWA) initiative and the concept of a Nexus Approach to environmental resources management.

This was followed by a comprehensive review of the social, technical, and cultural dimensions of wastewater use and perceived risks of wastewater irrigation by experts. The technological basics of water reuse, the need for policy integration, and the health aspects of wastewater use were also explored.



All presenters also participated in a panel discussion moderated by **Dr Olfa Mahjoub (INRGREF)** and **Prof. Hettiarachchi** to answer questions raised by members of the audience. On the second day, an excursion to the rural and agricultural area in the Nabeul Governorate (60 km from Tunis) took place.

The proceedings of the international workshop presented here do not necessarily follow the introduced agenda schedule. The experts' contributions are thus reported in a topic-related manner. This will help the reader to better conceptualise the challenges, opportunities, and solutions for implementing SUWA in Tunisia.

Section 2: Safe Use of Wastewater in Agriculture (SUWA) and the Nexus Approach

2.1 The Nexus Approach

In the inaugural session, **Prof. Hiroshan Hettiarachchi (UNU-FLORES)** explained why the Nexus Approach is important for UNU-FLORES, and the value of looking at the sustainable use of wastewater to better understand this approach.

UNU-FLORES considers the material resources perspective of the Nexus Approach, particularly promoting the integrated management of water, soil, and waste. The question that arises: why the Nexus Approach of Water-Soil-Waste (WSW)?

An essential key to sustainable development, the WSW Nexus Approach is the tool to enhance its benefits. The beauty of the Nexus Approach lies in its practicality and policy-oriented thinking.

"We should look for multiple paths when sustainability has to be addressed. One single approach will not work in the long run. In this perspective, the Nexus Approach could help substantially."

– Prof. Hiroshan Hettiarachchi, UNU-FLORES

The Sustainable Development Goals (SDGs) agreed upon by Member States of the United Nations (UN) represent a way to pave sustainability worldwide. Among the 17 SDGs, four are related to water, soil, waste, or a combination of them. This unmistakably implies that there is more work to be done to convince Member States to implement this new kind of thinking.

2.2 Safe Use of Wastewater in Agriculture (SUWA)

Prof. Hiroshan Hettiarachchi (UNU-FLORES) explained how the SUWA initiative is closely related to the Nexus Approach advocated by UNU-FLORES for the integrated management of water, soil, and waste. This management principle is aimed at maximising synergies. SUWA is an excellent example of explaining how beneficial and efficient this combination can be. The importance of integrated resource management was emphasised by Prof. Hettiarachchi where he stated that it pushes us to think about the long-term strategic visions and link policies at different levels in order to ensure administrative coherence. When applied to wastewater use, the ultimate solution of the Nexus Approach could also alleviate water shortages faced by the agricultural sector in many regions.

Prof. Hettiarachchi pointed out the effects of foreseen changes on agricultural productivity (reduction in crop yield) within the next 60 to 70 years. With these scenarios, food security cannot be guaranteed, and uneven food distribution will be further exacerbated worldwide. SUWA is an excellent example that makes clear the importance and benefits of integrated management of water, soil, and waste, which is defined as the Nexus Approach. The process begins in the waste sector, but a sustainable management model can make it relevant and important to the other resources such as water and soil. Proper management of wastewater provides not only a secondary source of water for some specific use but also nutrients that can be fed back to the soils. These synergies can make an important contribution towards achieving food security as water, soil, and waste are three key environmental resources involved in crop-based food production.

Even though over 20 million hectares of land are currently irrigated with wastewater, a greater percentage of this practice is not based on any scientific criterion that ensures the “safe use”. The experience of industrialised countries shows that even with advanced wastewater treatment, technologies struggle to address all the risks. Indeed, despite the availability of technologies, many areas of the world still struggle with the selection and use of sustainable technologies that provide swift responses to ensure the proper safety measure for communities.

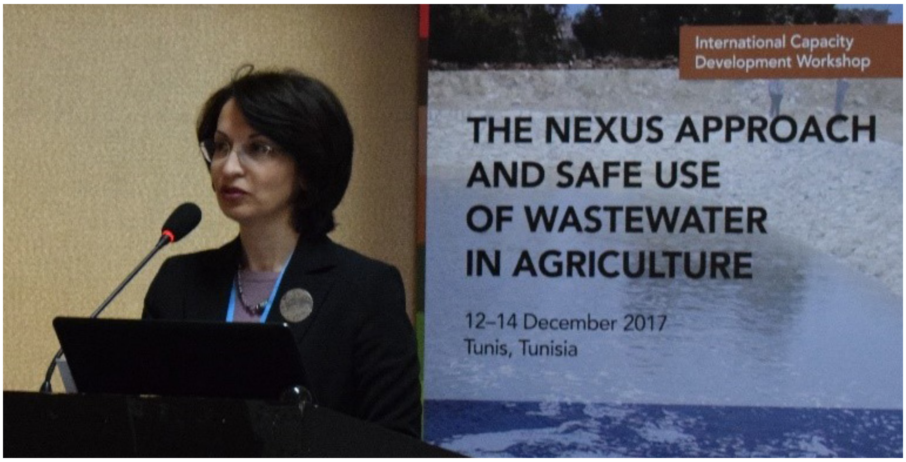
We should think about the long-term strategic visions and link policies to ensure administrative coherence. When applied to wastewater use, the Nexus Approach could be a solution to water shortages – the reality of many agricultural sectors, including Tunisia. Tunisia is the 33rd most water-stressed country in the world and makes use of 80% of total renewed freshwater. Water scarcity only adds pressure on water demand in agriculture. Faced with these facts, and in the context of the Water-Energy-Food Nexus, SUWA brings numerous benefits; it improves food production and nutritional status, reduces fertiliser use, reduces energy consumption for groundwater pumping, and reduces pressure on freshwater resources.

Whenever we start discussing a project or problem to solve, we try our best to involve decision makers from the policy sector because that will be the only way to realise the project. The Sustainable Development Goals (SDGs) set by the United Nations were also introduced. Among the 17 SDGs, four are directly related to soil, water, agriculture, waste, and their combination. This clearly means that there is more work to be done to achieve them by 2030.

Section 3: Understanding the Problem

3.1 Status of Wastewater Reuse in Irrigation in Tunisia

Dr Mahjoub (INRGREF) started her talk with gladly highlighting that almost all the institutions and organisation representatives involved in wastewater use had been invited to take part in the workshop, which would support a positive interaction on SUWA and the Nexus Approach among the audience. Afterwards, she started with some statistics to give an insight into the general situation in Tunisia. She described the current socio-geographic aspect of the country and connected it with the challenges that it faces for sanitation and water supply for the year 2030.



Tunisia is a country of 11.3 million inhabitants (2016) of which 68% are living in the urban area; around 90% of the population in this area are connected to the sewer network operated by the National Sanitation Utility (ONAS). The remaining population (32%) live in rural areas, and almost the total (99%) are either connected to improved (92%) or shared (7%) sanitation systems. Only 1% do not have any sanitation system and are practising open defecation.

The sewage effluents produced in Tunisia are from the urban area (83%) of which 98% is treated in wastewater treatment plants (WWTPs). Currently, there are 115 WWTPs active in the whole territory, among which 78% are equipped with activated sludge process (with low and medium organic load). Hence, the WWTPs are producing secondary treated effluents estimated at 270 Mm^3/year; only a few WWTPs are equipped with tertiary treatment which is hardly operating.

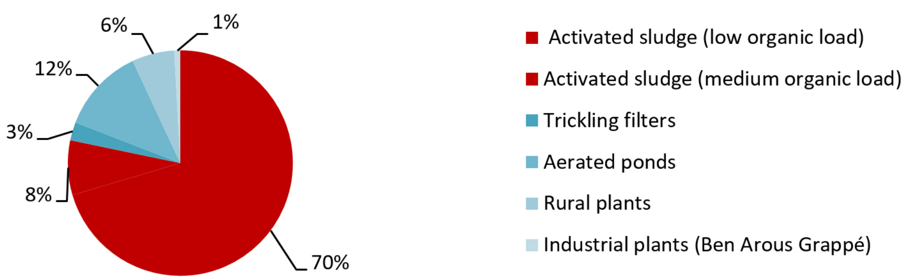


Figure 1: *Distribution of the treatment processes applied in treatment plants*

Tunisia is one of the MENA countries with a high level of water stress.. Approximately 83% of the population suffer water shortages. However, about 75% of the treated wastewater is discharged into the receiving environment. The situation is expected to worsen by the year 2020 as the maximum abstraction level of freshwater resources will be reached (4,600 m^3 out of the 4,800 Mm^3). As with many other countries of the MENA region, the major consumption of freshwater in Tunisia is dedicated to the agricultural sector consuming 80% of the available water resources. However, 20% of the water resources, especially groundwater, are exploited unsustainably thus representing an environmental, social, and economic threat to the country.

In connection with the achievement of the Sustainable Development Goals (SDGs) by the year 2030, Dr Mahjoub mentioned that water and sanitation have to be guaranteed in the country and the sustainable management of water resources pursued through the SDGs. Achieving SDG6 in the country is expected to assure:

1. Universal and equitable access to drinking water
2. Access for all to adequate sanitation and hygiene services and end of open-air defecation (2030)
3. Improved water quality (water pollution reduction, no dumping of waste, and minimising emissions of chemicals and hazardous materials)
4. Reduction of untreated water by 50% and significant recycling and safe reuse of water at the global scale

Accordingly, Tunisia has included the SDGs agenda in its National Development Plan (NDP) (2016–2020). Despite the good intentions of the SDGs, challenges and conflicts may arise for Tunisia due to the expected drop of the water share per capita per year, down to 360 m^3 for the year 2030 compared to the current figure of 450 m^3 estimated to be already below the baseline of 1,000 m^3, thus indicating an absolute water scarcity.

To cope with water shortage, Tunisia has launched a strategic study for the whole water sector called "Water 2050". Amongst the priorities aiming at using non-conventional water resources, the study will promote the use of wastewater. For that purpose, a thematic group on "wastewater reuse" was established. One of the fundamental statements is the need for wastewater to be used/recycled. The reuse/recycling is indeed a powerful solution to reduce the negative impacts of drought and water pollution, and to increase its intrinsic positive aspects for a sustainable economy as water and nutrient provisioning or energy production.

National standards related to effluents quality released into receiving waters and for reuse for agricultural purposes

Wastewater use in Tunisia is going through various challenges that need to be overcome. One of them is related to the regulatory framework. The national standard for the discharge of wastewater to the receiving environment (NT 106.02, 1989) is divided into three domains: maritime, hydraulic, and sewerage system. The purpose of this standard is to define the conditions for the effluents discharge subject to authorisation in the water environment (Decree No 85-56 of 2 January 1985) and characteristics for the discharge of effluents into the public network (Decree No. 79-768 of 8 September 1979).

The NT 106.02 (1989) sets the minimum requirement standards for the quality of the effluent according to its receiving environment whether it is maritime, public hydraulic, or public pipelines. According to these standards, the release thresholds for 54 physicochemical and bacteriological parameters including heavy metals and some organic micropollutants (hydrocarbons, pesticides, PCB/PCT, and phenols) in the effluents have been defined.

When not discharged, treated effluents are used for irrigation, and the basic parameters to be frequently monitored are the BOD5, COD, and total suspended solids (TSS). Nevertheless, several WWTPs are not in compliance with the standards because of: the illegal discharge of industrial effluents in the sewer system, WWTP overloading, low enforcement of regulations, the ageing of WWTPs, and so on.

Within the history of the regulatory framework of wastewater management, the first time that water reuse was mentioned is in the Water Code (1975) that prohibits not only the use of raw wastewater in agriculture but also the irrigation of garden crops, whether they are eaten raw or cooked. This law was revised, amended in 2012, and recently approved. In 1989, a Decree was formulated and contained the conditions of reuse in agriculture under the Tunisian standard for agricultural reuse, NT 106.03 (1989).

Nowadays, the used treated wastewater has a volume of 62 Mm^3 of the total originated from 66 WWTPs. Among these WWTPs, 30 are using their treated water for irrigating agricultural areas, 8 to irrigate 10 golf courses, and 2 to replenish coastal aquifers (still operating at pilot scale) and 1 WWTP in Gafsa for industrial reuse by the Tunisia Chemical Group for the phosphate industry. Unfortunately, only 20 Mm^3 of the total treated water are used for irrigation purposes. The volume corresponds to merely 1% of the needs for irrigated agriculture. Apart from that, WWTPs are reusing the effluents to irrigate green areas and gardens in their surrounding environment.

Irrigation with treated wastewater

Tunisia practises the direct reuse of treated water, which implies a use after transfer from the point of production to the point of reuse without rejection in the receiving environment. Very often a regulation basin is installed downstream of the WWTP, then the effluent passes in the distribution network to be diffused in the irrigated area.

Currently, the total irrigated areas cover 8,100 hectares including 6,150 hectares of partially irrigated perimeters which represent 76%; this is the case of the area of Borj Touil where 450 hectares are currently irrigated out of the 3,200 hectares initially planned. As a matter of fact, 24% of the area equipped with irrigation devices is not irrigated. The equipped areas increased significantly and then stagnated during the years 2010s. The areas exploited and the volumes used are highly variable and have declined sharply.

Environmental and health risks of the wastewater use of today

Major risks are coming from the poor quality of treated wastewater. In 2013, only four WWTPs had effluents complying with all thresholds of water quality parameters regulated by the national standard of reuse 106.03 (1989), and 80% of the WWTPs had two or more parameters exceeding the maximum threshold value. Globally, the rate for WWTPs parameter non-compliance was 52–70% for BOD, 52–77% for COD and 35–40% for total suspended solids, respectively. Phosphates and nitrates were not in accordance with the maximum threshold values for all existing WWTPs in Tunisia.

Salinisation of soil is one of the major problems encountered in Tunisia when municipal wastewater is used in agriculture. The accumulation of heavy metals in soil and plants when industrial wastewater is discharged into the sewer system and then applied to fields may occur.

This risk is unavoidable in the long term if wastewater is not treated properly. It is an example of the recent accumulation of emerging contaminants like estrogenic hormones and pharmaceutical compounds (antibiotics) in groundwaters due to direct or indirect use of wastewater in agriculture.

Antibiotics like sulphonamides, erythromycin, and macrolides were found in the aquifers of the irrigated area of Oued Souhil (unpublished results) in relevant concentrations similar to their concentration in wastewater, confirming the negative role that poor treatment and inadequate agricultural practices may have on the environment.

Despite the ban put on the irrigation of marketable raw consumed crops, major health risks are related to the transmission of pathogenic bacteria from wastewater to farmers via the handling irrigators. Indirect contamination can also be extended to farmers' families, their entourage, or to the consumer that is the final handler of the produce.

The lack of awareness of the health risk related to wastewater handling needs still to be incorporated into the good practice of farmers’ working activities. Nevertheless, no vaccination nor regular sanitary control are guaranteed to the farmers.

Dr Mahjoub underscored that the use of wastewater in irrigation might have some negative impacts in the long term if good agricultural practices are not in place. The transfer of hormones and pharmaceutical compounds is of concern and has been observed in some irrigated areas.

The results to be published soon by Dr Mahjoub’s research team showed the transfer of antibiotics to groundwater under surface irrigation with secondary treated wastewater. The presence of antibiotics could be problematic to the environment and living organisms.

Dr Mahjoub concluded her talk by underlining that the government is currently establishing an action plan to cover various uses of wastewater. She underscored the importance of applying a tertiary treatment for the mitigation of microbiological risks and health protection of the end-users. In addition, she highlighted the importance of risk evaluation related to reuse under various domains like aquifer recharge. The occurrence of contaminants of emerging concern should be addressed under different practices.

3.2 Agricultural Activity and Water Resources in Korba, Tunisia

Eng. Samir Gabsi represented the governorate of Nabeul, which was created on 21 June 1956 and called Governorate of Cap Bon from 25 September 1957 to 17 September 1964. It is one of the 24 governorates of Tunisia. It is located in the northeast of the country and covers about 2,822 km with a population of 787,920 inhabitants in 2014. The main town is Nabeul (formerly Grombalia, between 1957 and 1964). Administratively, the governorate is divided into 16 delegations, 24 municipalities, 21 rural councils, and 99 *imadas*.

Influenced by its advanced position in the Mediterranean and by the transverse orientation of its main relief (Jebel Abderrahmen), as well as by the presence of a corridor allowing the penetration of currents of the North-West (NW) sectors, Cap Bon profits from a Mediterranean climate characterised by irregular rainfall and relatively high-temperature amplitudes. Annual average rainfall is about 500 mm in Kelibia and 463 mm in Grombalia.

In general, the western regions are slightly more endowed with water thanks to the location of Jebel Abderrahmen. In fact, the dominant air masses in autumn are disturbances from the east and southeast, giving more rainfall on the east coast, while the prevailing winter and spring winds are from the west and north, generating more rainfall on the west coast. Cap Bon is the windiest region of Tunisia: it records on average 300 days of wind per year. Dominant NW winds can

frequently reach, during the fall and winter, speeds of 80 to 100 km/h. The speeds are accentuated by the configuration of the relief, which transforms the Sidi Daoued-Kelibia furrow in winter into a real corridor of the passage of air masses thus causing an increase in the speed of the winds.

Cap Bon has a humid, sub-humid, and semi-arid climate. This bioclimatic diversity is the combined result of the geographical alignment of the peninsula, the proximity of the sea, and the presence of Jebel Abderrahmen. The whole of the west and east coastal fringe going from Korbous to the southern limit of Menzel Temime presents a variant to warm winter. The southeastern region of Cap Bon, far from the influence of Jebel Abderrahmen, is located in the semi-arid upper floor, open to the warm southern currents, which brings it closer to the climate of the Tunisian Sahel.

The governorate of Nabeul produces 15% of the national agricultural production. Crops are grown on 246,000 hectares, which is 4% of the country. In addition, 41,000 hectares are irrigated, which increases the productivity of the agricultural sector. This sector is developing strongly and is characterised by an increase of 11% per year. The investment in this sector rose from 427.8 million dinars in 1997 to 583.3 million dinars in 2000, an increase of 36%, and exports of agricultural products and food have doubled between 1996 and 2000.

Cap Bon produces 80% of the grapes of Tunisia on 13,500 hectares, out of which 2,230 hectares are dedicated to table grapes. Production is 48,000 tonnes (2005), out of which 11,000 tonnes are table grapes (usually *Muscat* from Italy).

Korba is a delegation of the governorate of Nabeul. In 2004, it had a population of 60,564, including 30,911 men and 29,653 women and 13,649 households and 15,630 housing units.

Water resources consist of northern waters (around 84 Mm^3), RUT 32 Mm^3, surface waters around 150 Mm^3, underground waters around 216 Mm^3, and groundwater of 183 Mm^3.

There are five large dams with a total storage capacity of 50 Mm^3, including a dam in Korba, Chiba with a storage capacity of about 5.5 Mm^3 and serves an irrigated public perimeter of about 750 hectares.

There are 35 hill dams with a total storage capacity of 35 Mm^3. Besides, there are two dams on Korba hills with a storage capacity of 1.5 Mm^3 (Hannous and Djerida). These two dams are currently exploited in agriculture by direct pumping after a prior authorisation of the administration. There are 57 hill lakes with a total capacity of 5 Mm^3. There are four hill lakes in Korba with a storage capacity of about 0.6 Mm^3 operated by direct pumping after authorisation of the administration.

The renewable underground resources of the governorate of Nabeul are distributed among six aquifer systems including groundwater and deep aquifers. Most of the Cap Bon aquifers are in high demand and are under increasing operating pressure because of increased development, which has been known for a long time, especially on the agricultural front.

The Korba delegation occupies the eastern coast where the water table covers an area of approximately 390 km^2. The renewable resources of this aquifer are estimated at 50 million m^3 per year. Overexploitation of the aquifer is about 190% in Hawaria, 180% in Grombalia, and 118% in Korba. There are 29,400 wells including 2,300 wells in Korba, and 1,844 boreholes including 105 boreholes in Korba.

Irrigated perimeters in Nabeul cover 49,200 hectares, out of which 27,000 hectares (55%) are public perimeters. The Korba Region covers about 5,900 hectares of irrigated area, which represents 34% of the UAA including 1,800 hectares of public irrigated perimeters from the waters of the dams (Chiba and Lebna), public boreholes, and Madjerda-Cap Bon canal water, and 4,100 hectares of private perimeters irrigated through deep water tables.

The perimeter of Chiba covers an area of about 750 hectares characterised by the high motivation of farmers and the high degree of technicity which were often facing the problem of insufficient water resources to meet the needs of a very intensive farming system.

This constraint is now lifted after the connection of the dam, Chiba with the waters of the North; a connection that will allow the transfer of up to 1.5 Mm^3/year to the dam during the period of inactivity of the irrigation network. This transfer will be reinforced in the near future by the Chiba dam project, the work of which has just been completed, which will give greater flexibility to the filling of this dam.

Chiba's public irrigated perimeters are currently managed by three Groupements de Développement Agricoles (GDA) (GDA Tazarka, 216 ha; GDA of Beni Aychoun, 194 ha; GDA of Sidi Daas: 120 ha).

Safeguarding scope of Korba-Menzel Temime

The Korba-Menzel Temime Safeguarding Area (KMT) is fed from Medjerda-Cap Bon Canal (CMCB), the total flow of which is allocated to this area.

The total area of this perimeter is 1,600 hectares, out of which almost half (825 ha) is occupied by the Diar Hojjej perimeter of the Korba delegation and managed by GDA Diar Hojjej, while the rest is part of the Mida delegation and includes the two perimeters of the Lebna village. Water volumes pumped at GDA Korba by CRDA Nabeul decreased in 2016. To fill the water deficit in the three perimeters and to meet the water needs of vegetable crops, a diesel station has been installed at the Lebna dam reservoir since 1999.

Vegetable crops and strawberries essentially characterise the irrigated perimeters of Korba. Concerning the cultivation of trees, citrus is dominating with 800 hectares, of which 600 hectares exist in private irrigated perimeters.

In the Nabeul governorate, treated wastewater is used mainly for irrigation. At present, unconventional waters, that is 2% of the total area of the irrigated public perimeters irrigate 558 hectares. They are located in the delegations of Nabeul, Dar Chaaben, and Beni Khiar served through two wastewater treatment plants, namely that of Dar Chaaben and Nabeul which treat approximately 7.2 Mm^3 annually; the volumes pumped for irrigation are 2 Mm^3 (28%).

Currently, artificial recharge with treated wastewater is only carried out in Korba by injecting water from the Korba WWTP into three infiltration basins. The total volume of treated wastewater injected varies from one year to another and depends on the number of days per month and the number of hours per day of operation of the pumping station.

The volume injected during the year 2017 has improved significantly compared to the last three years but slightly lower than that of the year 2013. However, these volumes are still insufficient to mitigate the overexploitation of the water table and to slow down the salinity level especially since the treatment plant can produce up to 8,000 m^3/d.

3.3 Impact of Aquifer Recharge on the Agricultural and Ecological System

Eng. Tiba Haggui brought to the workshop knowledge on the aquifer recharge history of the Korba-Mida aquifer and its characteristics. The aquifer belongs to the Oriental Coast Aquifer, which borders with Jebel Abdurrahman in the north-west, El Hawaria Graben in the north-east, Grombalia Graben in the south, and the Mediterranean Sea in the south-east.

The analysis of rainfall data covering a period of 55 years of observation, this is from 1965 to 2015, showed a strong spatiotemporal irregularity. The average annual rainfall is of the order of 423.5 mm.

The plain of the eastern coast is constituted mainly of Mio-Plio-Quaternary deposit. The lower middle Miocene layer constitutes detrital deposits. It has two superimposed aquifer formations. A first layer constituted by the Plio-Quaternary filling dominated by sandy clay and underlying Pliocene sands, covers an area of 475 km^2.

The thickness of this formation varies from one place to another, but it does not exceed 160 m. A second aquifer formation consists of a set of Miocene and Oligocene layers. These layers are housed in sandy formations. The recharge zone of this groundwater is located in the outcrops of the Pliocene and Quaternary layers. Natural recharge comes mainly from the infiltration of precipitation. The agricultural activities practised in this zone are cultures that consume water.

The region hosts the food industry, textiles, dairy, and paper. These activities require large quantities of water supplied mainly by the quaternary aquifer and the irrigation water of the Medjerda-Cap Bon Canal, which connects the rainy areas of northern Tunisia to Cap Bon.

The aquifer system is operated by 9,468 surface wells, 7,664 of which are equipped with pumps. The total resources are in the order of 50 Mm^3/year. The operation exceeded 59.50 Mm^3/year, resulting in a levy rate of 119%. The deficit of 9.59 Mm^3 shows intensive overexploitation which results in a decrease of the piezometric level from where the inversion of the gradient is causing the diffusion of salt water.

Given this situation, within the framework of the PISEAU, a new pilot site was built in 2008 in the region of El Mida, with the objective of recharging the water table of the eastern coast of Cap Bon with treated wastewater from the STEP from Korba to form a permeability screen against marine intrusion. This project is sized for a volume of 2,000 m^3/day. The site is located 500 m north of the Korba wastewater treatment plant. It is 1.5 km from the coast and is at an altitude of 15 m.

Aquifer recharge is carried out via soil infiltration of treated wastewater from the Korba WWTP at the level of the three elongated basins with an area of 1,500 m^2 each, two of which are in simultaneous operation and one at rest.

The remaining time must then allow the soil to percolate the water and find its stock of oxygen contained in its pores. The residence period in the infiltration pond should be calculated to allow:

- Reoxygenation of the soil for the biodegradation of residual pollution;
- Surface de-clogging by biodegradation of surface deposits (retention of suspended solids and development of bacterial films); and
- The mechanical maintenance of the infiltration range.

The depth of the unsaturated zone is 15 m. The treated wastewater from the Korba WWTP was put into service with a volume of 0.0225 Mm^3. At the end of 2016, a total cumulative volume of 3.12 Mm^3 was recharged in the aquifer. The volume of treated wastewater highest recharged in the water table is of the order of 1.145 Mm^3 during the year 2016.

To monitor and study the effect of artificial recharge by treated wastewater, a cooperation programme was set up between the CERTE laboratory and the DGRE. There was information available on the last monitoring campaign in Korba for the period 2008–2012 and it showed that the monitoring strategy of the piezometric evolution of the recharge site is based only on three indicators:

1. Comparison of the piezometric maps of the aquifer at different times after the initiation of the recharge operation
2. Monitoring of the salinity of the waters
3. Monitoring of physico-chemical and bacteriological quality

The piezometry of the area shows a weak piezometric rise in the south-east to north-west direction. The low water level is instead present in the northwest. The groundwater flows diverge from the seaside towards the centre of the piezometric depression.

At the level of the monitoring wells, monitoring showed three main phenomena:

- An increase in the salinity of the water table is recorded mainly at the well, which is further from the recharge site and located mostly on the north-west side of the recharge site;
- A decrease in salinity is recorded at four wells 176, 56, 64, and 31, which are located near to the seaside, west from the recharge site;
- Salinity stability of the waters of the water table is recorded at the wells which are located on the east side of the recharge site.

Physico-chemical and bacteriological water quality monitoring is carried out by a monthly sampling of 13 control wells. These analyses concern the physico-chemical qualities, the contents of major and trace elements, heavy metals, nutrients, organic, and bacteriological. The aquifer presented an elevated microbial pollution caused by high levels of faecal coliforms and faecal streptococci. The results of the analyses of the year 2015 show:

- High levels of COD that reach 184 mgO2/l at well 65 at the date of 01/09/2015;
- High levels of BOD5 reaching 181 mgO2/l at well 171 01/12/2015;
- High nitrate concentrations above 50 mg/l as of 03/06/2015.

Section 4: Policy and Health Aspects

4.1 Importance of Quantifying Health and Safety Aspects

The picture provided by the stakeholders and the first round of discussions among participants clearly demonstrated that a number of sociopolitical challenges needed to be addressed before a safe practice of wastewater use would be ensured in Tunisia. Addressing this gap, Dr Serena Caucci opened her speech about the importance of participatory approaches in quantifying health and environmental aspects of wastewater use before integrated policies may be implemented.

Dr Serena Caucci (UNU-FLORES) presented on the correlation between wastewater management and health aspects in relation to the use of wastewater in agricultural practices. She highlighted the necessity of an appropriate co-design of wastewater management that would consider health and technical expertise as well as agriculture practitioners. In her talk, Dr Caucci highlighted how wastewater could be a resource for agriculture in a time of water scarcity, but also a risk for human safety. Farming accounts for 70% of the global human water abstraction and is planned to increase with the growing needs of food security. Local communities face an urgent need to find alternative solutions to buffer scarce water availability for crop irrigation and the negative effect of this situation on their economy. One of these solutions is to apply wastewater in agriculture. The use of wastewater in agriculture goes beyond the single benefit of an alternative source of water provisioning. Wastewater is a provider of nutrients necessary for plant growth and a replacement of mineral fertiliser. Unfortunately, if not properly managed wastewater can also be harmful for both human and the environment.

After having briefly introduced examples of wastewater use in regions of the world like Asia, Mediterranean Area Europe, and North America, she highlighted that the technologies and treatment to make wastewater safe for agricultural purposes already exist and are fairly accepted both by the scientific and technical/operational communities of developed countries. Such technologies are indeed able to comply with standard microbiologic and physico-chemical requirements. Nevertheless, the concentrations and the nature of the contaminants in wastewater define the treatment that needs to be applied before disposal in water bodies. Traditional wastewater treatment plants had the goal of removing conventional pollutants, like organic and inorganic compounds, as well as the reduction of microbial load but failed to remove contaminants of emerging concern in their effluent.

The decision on whether to replace the conventional or other non-conventional water sources with reclaimed wastewater for agricultural irrigation primarily depends on the purpose of reuse and it has to be based on awareness of involved stakeholders. Reuse should aim at the minimisation of risk to acceptable levels for both public health and the environment. Moreover, when thinking of sustainable solutions, the application of such innovation has also to be weighed against foreseen economic benefits.

In developing countries, poorly treated wastewater in agriculture could represent a clear threat to public health due to microbial virus-based infections that could indirectly affect public health via wrong irrigation practices and/or consumption of microbially contaminated crops. In these cases, the World Health Organization (WHO) has indicated that the risk of disease caused by pathogens or toxic compounds can be minimised via a reduction in farmers' and consumers' exposure to untreated wastewater.

Although advanced wastewater treatment has already been tested in the Mediterranean countries, reclaimed wastewater is still discharged into freshwater bodies or the sea and not used for agricultural irrigation. The missing continuity and consistency on wastewater use risk assessment makes the topic of reuse a difficult one for policymakers and practitioners. The water quality is of extreme importance in agricultural or landscape irrigation and the parameters defining water quality are unfortunately not often measured nor systematic monitoring strategies are planned within the wastewater treatment of municipalities. Consequently, no risk assessment for public health can be inferred nor destination of use for effluents thoroughly planned. The uncertainty of the effluent quality strongly influences the acceptance of water reuse among locals. The application of wastewater reuse in agriculture requires then not only technological knowhow but also deep understanding of the social and cultural barriers and the monitoring strategies are a fundamental tool for increasing trust in water reuse safety measures. While we might already have the technology and sufficient knowledge to capacitate sustainable wastewater management and use in agriculture, what we do really need is the policy and stakeholder integration in the capacitation process, particularly with regard to regulation and monitoring programmes. This will ensure a clear balance between health and economic benefits regionally.

Dr Caucci introduced management strategies for water reuse in crop production and safety measures for farmers during its application. The WHO and SUWA guidelines seemed to be familiar to the participants, but participants were not able to state whether the actual guidelines could be implemented and how. Despite the demonstrated high interest in the aspect of water provisioning within SUWA, dominant in the discussion was the significance of health aspects as a priority for effluent quality monitoring in the context of agricultural water reuse in Tunisia.

4.2 Nexus Approach: The Vision of Harmonising the Conflict of Interest over Water Resources in the Water, Energy, and Agriculture Sectors

The Water-Energy-Food (WEF) Nexus is pivotal to sustainable development. Demand for all three domains is increasing, due to global population growth, rapid urbanisation, different diet habits, and economic growth. Agriculture is the largest user worldwide for freshwater resources, and more than one-quarter of the worldwide energy is used for food production and its supply. The rooted linkages between these domains require a proper integrated approach to ensuring water and food security, and sustainable agriculture as well as energy production.

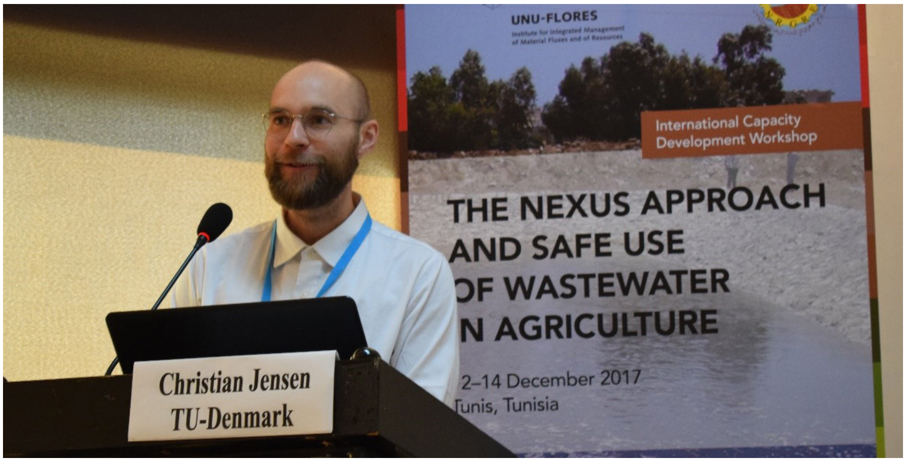
In this context **Ing. Manfred Matz (GIZ)** exemplified the role of Nexus Approach as a major player for the maintenance of natural resources to keep them as balanced as possible. The extreme relevance of the water supply and demand in agriculture is clear to Tunisia. Extended dry periods and overuse of blue waters make Tunisia lose 19 million m^3 of dam storage capacity annually, thus reducing its ability to supply water to agriculture and other users. Overall, the estimated damage costs associated with irrigated agriculture varies within USD 6–62 million (0.17–0.2% of GDP). With this threatening scenario, the Tunisian state has made impressive progress on the implementation of treated wastewater use in agriculture compared to other neighbouring states of the Mediterranean. The use of treated wastewater for irrigation has indeed reached 7,440 ha including natural parks, golf courses, and public gardens. However, despite the efforts made by the country to increase wastewater reuse in their agricultural activities, more than one-third of overall treated wastewater for irrigation is of poor quality. Water scarcity and pollution negatively affect the agricultural productivity, especially in the Borj Touil and Mornag areas. Mornag is located in the north of Tunisia and distant 20 km from Tunis City. The area is known for its intense agricultural and industrial activities.

To improve the hydrodynamics and water quality of local groundwater, artificial groundwater refill (MAR) is practised with surface water in the Khlédia area. The whole region is irrigated by groundwater and Mejrda-Cap Bon Channel (M-CB.C). The Mornag region also includes important industrial parks Ben Arous and Rades, where solid waste is a heavy source of pollution (especially heavy metals). The pollutants are indirectly reintegrated to the local agricultural area. In this area, the water characteristics used for irrigation changes from farm to farm because the farmers use different sources of water of different water quality. Determining the effect of water quality changes used for irrigation on organic matter (TOC), pH, and salinity (E.C.) of soil is thus necessary, as well as the evaluation of heavy metals pollution levels (Ni, Cr, Pb, Cd,

Cu, Zn) in surface sediments of Mornag irrigated areas. This will allow farmers and locals to get awareness of the impact of industrial activities as well as poorly treated reused water on soil pollution. No changes can happen without knowledge. People believe that the "water-related problems" are only matters for governments. This is not the case. Water pollution is a responsibility of every single person, too.

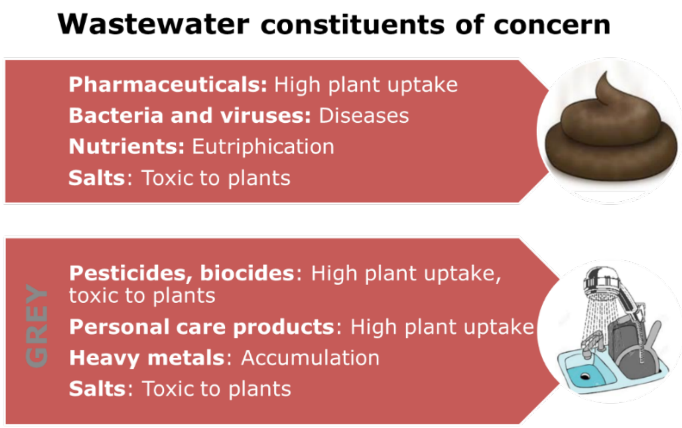
A criticism to the WEF Nexus nevertheless appears evident from previous experiences: the perspective on how water is contemplated has to change radically. Until now the perspective on sustainable approaches have been through the water lens and not in an integrated manner as part of the intimate connection of other natural resources such as soil and waste. To achieve that, there is thus the need to act at three levels: governance, technology, and community. Subsidising waterways instead of freshwater only is one possibility. When water will become part of the everyday economy of people, self-awareness on water uses will increase and consciousness to the rationale behind wastewater treatments, too. Increasing awareness should be the next step. The common saying "prevention is better than cure" is often popular among communities in Tunisia. Awareness of the risk of water pollution could be done, for example, by increasing the level of consciousness and acceptance in this country about water.

Section 5: Looking to the Future: How to Predict and Improve Food Safety

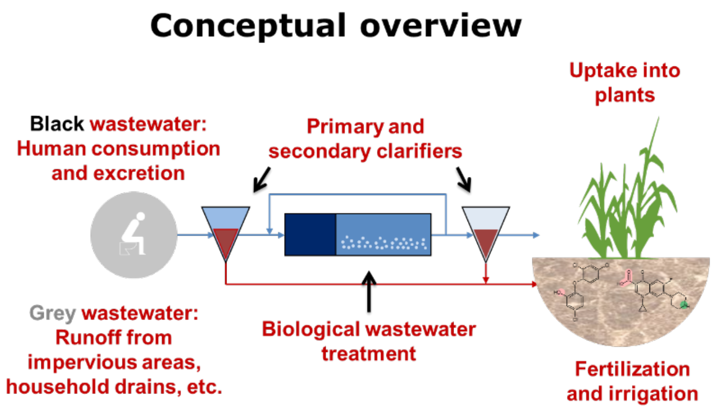


5.1 Models for Plant Uptake of Chemicals from Water Reuse

As a solution to water scarcity and rapid groundwater abstraction, the use of reclaimed water for agricultural irrigation has been practised in arid and semi-arid countries for years at different rates of success. Wastewater today irrigates between 1.5% and 6.6% of the global irrigated area of 301 million ha (1.2 million sq. miles) and about 10% of the world's food is produced using wastewater. Despite the direct benefits, there are growing health concerns around this practice because unregulated water reuse can often cause waterborne diseases due to continuous soil and aquifer pollution. Down-the-drain emissions were recognised as one of the major sources of chemicals in the environment, and the generic WWTP simulation model SimpleTreat was recommended for their prediction. Moreover, contaminants present in reused water indeed can accumulate in soil and there is probability of moving within the food chain or into the water cycle.

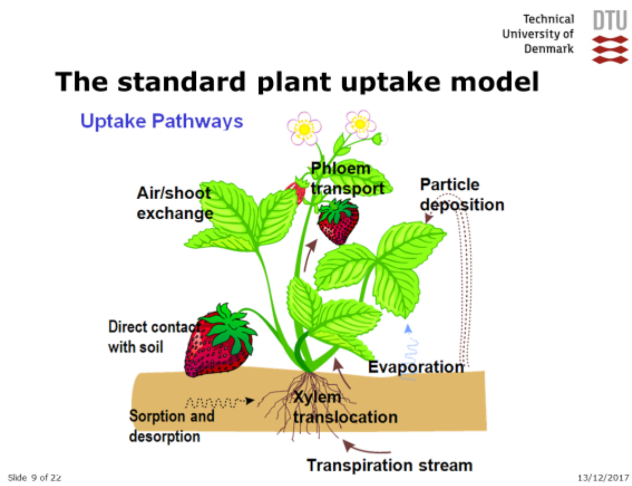


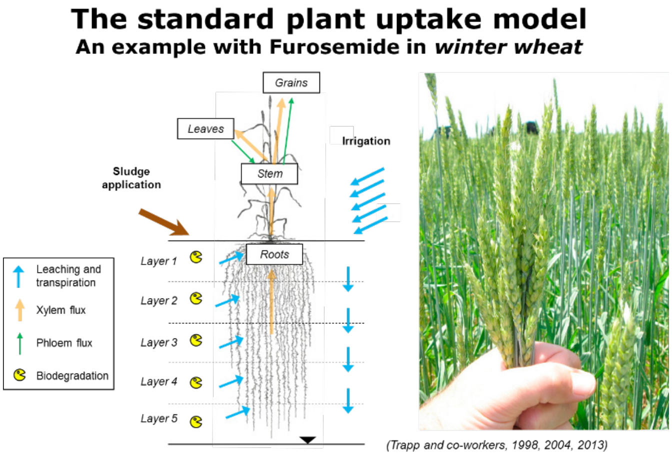
Determining chemical contaminant uptake by plant roots and their translocation into the leaf/fruit tissues is critical not only for assessing remediation strategies of contaminated fields such as phytoremediation or monitored natural attenuation (MNA) but is also crucial for the assessment of human and environmental health risks related to food/crop consumption.



Chemicals are known to translocate from roots to the plant via xylems along with water molecules that are used in the transpiration process.

This process implies that the longer the plant is exposed to water, the greater is the amount of water transpired and as a consequence, the more contaminants are taken up by the plant. The concentration of contaminants accumulated in the above-ground plant tissue though is not directly related to time, but it depends on processes like metabolism, volatilisation, and plant growth rate. Such parameters contribute to the reductions of contaminant concentration in crops. Numerous models have been developed to explain the uptake of contaminants into a wide variety of plants (e.g., Trapp 2000a, Collins et al. 2006, Trapp et al. 2007, Legind and Trapp 2009). Validating how *transpiration* and *growth* are related to *uptake* and *toxicity* of organic and inorganic chemicals can be a great tool to predict how crops exposed to various concentrations of pollutants can accumulate in the plant and thus derive from it their toxicity level for human consumption.





The prediction of interaction between transport and uptake of pollutants in plants is still difficult to model. The bottleneck resides in the lack of methodologies that directly assess the functioning of plant roots in complex media such as soil system. The Technical University of Denmark (DTU) is a pioneer in such a field and **Ing. Jensen (DTU)** described in the workshop one of the successful models developed in his department for transport of pharmaceutical pollutants fate (furosemide—FUR) from the effluent to winter wheat via modelling simulation (Polesel et al. 2015). Excreted chemicals like pharmaceuticals undergo incomplete elimination in municipal wastewater treatment plants (WWTPs) and are released to surface water via treated effluents.

Results suggested a significant release of FUR in the WWTP effluent and a high translocation potential to wheat was predicted up to a concentration of 4.3 μg kg_{DW}^{-W} in grain. Irrigation was found to enhance the relative translocation of FUR to plant (45.3–48.9% of emission to soil). The prediction model was validated with experimental data for elimination in WWTP, bioconcentration in plant tissues. Models thus can be a useful tool to prioritise pollutants to be monitored and for an estimation of human exposure to trace chemicals via intake of food crops. Estimation of the risks and benefits of wastewater irrigation could ensure compatibility between current land-use activities and the future deployment of a water-wise economy. Risk estimation and monitoring tools such as the one developed at DTU can help to establish accumulation potential of down-the-drain chemicals in edible plants or estimate the potential human intake of chemicals via consumption of crops.

Section 6: Panel Discussion on Wastewater Use and Monitoring Aspects for Water Quality

***Question:** What do you think would be necessary to move forward and tackle the challenge related to water scarcity and pollution? How can we apply the Nexus Approach for water reuse in Tunisia? And what technologies can we use?*

- **Response from Manfred Matz:** What we need first is to change the social behaviour, politics at the leadership, administration, and users' level. Only in this way can we preserve water for future generations. There is a low awareness of problems related to water pollution from anthropogenic practices. A lack of knowledge is also a problem: people believe that the "water-related problematics" have to be a matter for governments only. This is not the case. Water pollution is a responsibility of every single person, too.

- **Comment from Awatef Messai (DGEQV, MALE):** Regarding water reuse, you said that the problem related to it is only qualitative. Unfortunately, it is not always the case in Tunisia. In Tunisia a survey was conducted among 960 farmers and a majority were found reluctant to use wastewater, irrespective of the effluent quality. Especially in the northern part of Tunisia, farmers having shallow aquifer do prefer conventional water, unlike farmers in the southern part of the country who are in water-scarce areas and have to reuse water, regardless of its quality. In addition, the restrictive list of crops allowed to be irrigated with treated wastewater referring to high market value crops, such as vegetables, make the farmers more reluctant toward the use of treated wastewater and push them to continue to irrigating their produce with conventional water.

***Question:** As previously described by Mr Matz, Tunisia has a lack of awareness toward water reuse, especially at the famers level. How would you combine awareness and implementation of the safe use wastewater in agriculture in Tunisia? Where is the trigger point?*

- **Response from Olfa Mahjoub (INRGREF):** Yes, farmers are indeed very reluctant with respect to water reuse. A study done by the Ministry of Environment has shown that in certain conditions water is of good quality to be reused. Thus, more in-depth work has to be done for behavioural change of communities with regard to implementation but I think there are concerning issues that are already resolved at the regulatory level. But it needs to be transferred and shaped around communities' needs. We need to strengthen the knowledge and monitoring and show to the population "there is no risk for them when using treated wastewater". Only in this way can we convince civil society and farmers to accept water reuse. Another sphere to take action is within governance. We need to make everyone feel responsible for the prevention of water pollution, we need to make water related to the daily economy of the people, and raise awareness on the safe use of treated wastewater in agriculture.

- **Comment from Tiba Haggui (DGRE, MARHP):** There is a need to implement the list of water quality parameters because the ones now present in the regulation are not sufficient and need to be revised. Farmers need good reused water quality for cash crops.

- **Comment from Awatef Messai (Ministry of Environment):** In addition to information on awareness, I would like to stress the fact that the Ministry of Environment has established a national communication plan and awareness strategy on the safe use of treated wastewater. A survey on farmers' knowledge on wastewater use was conducted, followed by an awareness campaign carried out in the northern, central, and southern parts of Tunisia. We monitored

the campaign's impact on the target population and as a result, we found that if well instructed, farmers started thinking rationally and taking safety measures such as wearing gloves. In relation to the water quality standards, as representative of the Ministry of the Environment, I can mention that we have already updated the regulation, but arbitration is necessary with the industries union. Such an organisation often tends to be rigid when confronted with normative changes. After finding a consensus, further standards will be published, which will focus on groundwater recharge, ecological services, and agricultural uses.

Question: *A comment about the recharge station of Korba: You said that around the recharge stations, there are farmers who irrigate crops with highly saline water. Do you see repercussions happening at the yield and quality level of the produce and especially for fruits? If so, how do the farmers handle this situation?*

Response from Samir Gabsi (CRDA Nabeul): I am not aware of this issue in Korba. However, as attenuation measure, farmers have installed small devices on the water pipes to desalinate groundwater. This is done only for 23 monitoring wells for water quality control.

Comment from Tiba Haggui (DGRE, MARHP): Yes, the crop yield is affected and is inversely correlated to the salinity of the irrigation water. Surveys revealed that farmers practise water blending (conventional and saline water) close to the Madjera-Cap Bon canal, and this is the case of large farms. The situation in Korba is alarming not only due to the salinity threatening freshwater resources but also because of the microbiological pollution of the aquifer which is clearly caused by its recharge conducted with poorly treated wastewater. Feedback from the Ministry of Health is required in this regard.

Comment from Souad Dekhil (DGRE, MARHP): I can provide some additional information on the updated picture of water reuse. The first experience started in 1965 on 1,200 hectares where citrus fruits are irrigated with treated wastewater. But unfortunately, out of the 8,500 hectares only 6,500 hectares are still using freshwater because they are located in the north. In other areas which are poorly exploited, like Mornag, irrigation with wastewater has stopped because of the poor quality of treated wastewater produced in the treatment plant.

Comment from Jamel Chellouf (DHMPE, Ministry of Public Health): For the aquifers, we have no regulations in force. For now, the Ministry of Health has no studies and no official communication regarding water pollution in Korba; we cannot be sure of the source of pollution. It could also be a result of agricultural activity. So, we cannot confirm that the groundwater contamination comes from the bad quality of the wastewater treatment plant.

Comment from Olfa Mahjoub (INRGREF): The source of pollution can be determined by scientific studies.

Comment from Mondher Mansour (ANCSEP, Ministry of Public Health): Yes, this is true. But we need ministerial studies to be conducted to take this information as true. No independent research can be used to formulate state decisions. Regarding wastewater monitoring, the overall strategy will be revised and updated. We want to address also the risk of exposure to pollutant for the population via food ingestion. The problem is that we have not developed the approach to do so.

Comment from Abdellaziz Zairi (INRGREF): To increase the use of treated wastewater we need better wastewater treatment technologies, including tertiary treatment in municipal wastewater treatment plants (WWTP). Even in places where secondary treatment is applied,

no monitoring is conducted and the water results to be of poor quality for agriculture (measurements done within the Agricultural Ministry monitoring). We cannot believe that a simple primary treatment is sufficient to have good water quality to irrigate cash crops and to have a real advance in the economy of farmers.

- **Comment from Awatef Messai (DGEQV, Ministry of Environment):** Increasing level of treatment in WWTPs is a problem for the Ministry of Environment because there is a high increase in costs and energy consumption.

- **Comment from Souad Dekhil (DGGREE, MARHP):** Investments are necessary to improve WWTPs and for the maintenance of structure monitoring measures to support the decision for new investments, altogether to support water reuse in agriculture or aquifer recharge strategies so as to support future choices.

- **Comment from Tiba Haggui (DGRE, MARHP):** The 'who does what' is the problem here. How do we convince farmers to use such methods? They could use a higher level of treatment and sensitisation to avoid the risks.




Comment from Jamel Chellouf (DHMPE, Ministry of Public Health): The health service encourages the use of treated wastewater if it respects the basis and the sanitary rules. The human being is at the centre of the water-food-soil triangle, and it is necessary that standardisation complies with the sanitary regulation, especially with regard to the crops restriction list.

Question: *Are the contaminants revealed by the analysis made by the DGRE due to the artificial recharge of the aquifer or to other factors?*

Response from Tiba Haggui (DGRE, MARHP): Currently, we are doing advanced analysis in order to be able to differentiate the different sources of contaminations, and there will be a report that will be published soon, but based on what we currently know, we really believe that artificial refills are the major source of contaminants.

Question: *What are the methods used to assess the health risks of using treated wastewater? How do you collect information on the statistics of the disease/year, etc.?*

Response from Mondher Mansour (ANCSEP, Ministry of Public Health): Surveys were carried out with questionnaires by visiting farms of different types of agricultural crops, using different irrigation techniques (treated or conventional wastewater), and collecting the information that was used to compile statistics in the forthcoming report.

Response from Yasmine Mejri (ULT): We can use as a technique of prevention, kits for instantaneous analysis such as biosensors with polyclonal antibodies for detection of hormones, antibiotics, and active ingredients, also there is another technique, for example, WATCHFROG Laboratory (France), the first laboratory specialised in measuring the effects of disrupters endocrine and pollutants on the larva.

Researchers at the National Museum of Natural History and the CNRS wanted to develop an alternative method to replace laboratory animal experimentation. The hormonal mechanisms at these very young stages are identical to those of adult animals and are conserved through the evolution of species to humans. In order to translate these hormonal signals, a reporter system based on the expression of fluorescent proteins reveals the endocrine effect. The purpose of using transgenesis is to highlight the natural responses of embryonic organisms to disruptors without modifying their physiology or the functioning of their genome.

Comment from Jamel Chellouf (DHMPE, Ministry of Public Health): The Ministry of Public Health encourages the use of treated wastewater if it complies with the basic parameters and the sanitary parameters. Human beings are at the centre of the water-food-soil triangle, so it is necessary that any standardisation should refer to the sanitary regulation, especially that in Tunisia there is a list of authorised crops, which respect the conditions of hygiene, otherwise the use of wastewater is prohibited or restricted.

Comment from Othman Harbaoui (ANPE): Demanding information about the water quality at the WWTP next to the 3-polishing ponds, if there are data about the initial state of the water table in Korba.

Comment from Tiba Haggui (DGRE, MARHP): An advanced tertiary treatment is necessary in the WWTP before using wastewater in artificial aquifer recharge. The tertiary treatment would guarantee a low level of contaminants in the effluent of the WWTP.

Section 7: Closing

In this workshop, new solution pathways were suggested. Knowledge of the Nexus Approach was introduced to the local stakeholders. The approach considered the management of the natural resources, namely waste, soil, and water, in a holistic manner.

Data gathering is one of the bottlenecks for the development of such an approach. Often, information is either not publicly available or is retained by community-based associations and/or institution at the national or regional level. Similarly, lack of technical expertise and financial possibilities hamper the upscaling of SUWA, thus impeding the access of the farmers to a more sustainable agriculture.

In this workshop, knowledge and know-how were gathered in Tunis, Tunisia. Local and international experts were invited to give their perspectives on the current and future scenarios for water reusein the country. The workshop raised awareness of the benefit of the Nexus Approach for sustainable use of wastewater and aquifer recharge purposes. International experts highlighted the challenges and benefits of such practices, after having involved the audience in an open discussion.

During the closing session, the participants were offered another two opportunities to express their final thoughts. **Prof. Hiroshan Hettiarachchi** provided a brief overview of how the workshop programme unfolded. He summarised the two-day event and highlighted how the field trip has provided the international experts joining the workshop with a deep understanding of the reality in Tunisia. In Tunisia, the governmental and policy issues take over the economic and health aspects related to the reuse of wastewater in both agriculture and aquifer replenishment. Improving this situation is mandatory. Finding governance and implementation measures that foster the economy and at the same time guarantee public health is the direction which must be pursued. The Nexus Approach will help to pave the way forward.

Both the Ministry of Environment and the Ministry of Agriculture despite discrepancies between the two office governance policies expressed full support to UNU-FLORES and INRGREF for future activities which might be taken. **Ms Awatef Messai** expressed the intention of implementing collaborations between UNU-FLORES and the Ministry of the Environment and work toward the implementation of regulations for the monitoring of wastewater for potential use in agriculture in Tunisia.

In his closing remarks, given on behalf of the organisers, **Prof. Hiroshan Hettiarachchi** thanked all participants of the workshop. INRGREF's **Dr Olfa Mahjoub** concluded the event with her final expression of thanks. In her talk she mentioned the dynamic exchange of information between INRGREF and UNU-FLORES that had allowed for the success of the event. Dr Mahjoub expressed INRGREF's satisfaction with UNU-FLORES and stated that INRGREF is looking forward to the next phase of collaboration on the sustainable management of resources (namely water, soil, and waste) in Tunisia.

ANNEX LIST

Appendix 1: Field Trip

The trip was organised by INRGREF and CRDA Nabeul and allowed participants to discuss issues related to treatment methods, agronomic, groundwater recharge practices, and health issues related to environmental pollution and microbial in the topic of wastewater reuse. Existing, successful pilot projects on SUWA demonstrated how sustainable sanitation and wastewater reuse could co-exist in times of water scarcity in Tunisia. The itinerary included:

› *Regional Department for Agricultural Development (CRDA), Nabeul*
› *Wastewater Treatment Plant, Korba*
› *Aquifer recharge site, Korba*
› *Farm visit together with the Water Users' Association (GDA), Korba*

Appendix 2: Agenda of the Workshop

PROGRAMME HIGHLIGHTS

DAY 1 Tuesday, 12 December 2017

8:00–8.30	**Registration**
8:30–9:00	**Welcome and Introduction**
9:00–10:00	**Session 1:** The Nexus Approach and Safe Use of Wastewater in Agriculture (SUWA) The Nexus Approach in Tunisia
10:00–10:30	*Coffee Break and Networking**
10:30–12:00	**Session 2:** Status of wastewater irrigation in Tunisia Agricultural activity and water resources in Korba, Tunisia Importance of quantifying health/safety aspects
12:00–13:15	*Lunch Break and Networking**
13:15–14:45	**Session 3:** Impacts of aquifer recharge on the agricultural and ecological system Sustainable model for water reuse in agriculture
14:45–15:15	*Coffee Break and Networking**
15:15–16:15	**Session 4:** Discussion and Q&A
16:15–16:30	**Wrap-Up**

DAY 2 Wednesday, 13 December 2017

9:00–18:00	**Field Visit:** *Regional Department for Agricultural Development (CRDA), Nabeul* *Wastewater Treatment Plant, Korba* *Aquifer Recharge Site, Korba* *Farm Visit together with the Farmers' Association (GDA), Korba*

**UNU-FLORES has made plans to conduct interviews with attendees during the breaks to document their opinions and expectations.*

Appendix 3: List of Invitees to the International Capacity Development Workshop on "The Nexus Approach and Safe Use of Wastewater in Agriculture"

Name	Surname	Institution	Country
Zouhaier	Nasr	INRGREF	Tunisia
Abdellaziz	Zairi	INRGREF	Tunisia
Thameur	Chaibi	INRGREF	Tunisia
Haithem	Bahri	INRGREF	Tunisia
Olfa	Mahjoub	INRGREF	Tunisia
Amel	Jemai	INRGREF	Tunisia
Walid	Chmengui	INRGREF	Tunisia
Tiba	Haggui	DGRE	Tunisia
Samir	Gabsi	CRDA Nabeul	Tunisia
Manfred	Matz	GIZ-TUNISIA	Tunisia
Sonia	Mahmoud	CRDA Nabeul	Tunisia
Moncef	Teïb	CRDA Nabeul	Tunisia
Hichem	Ben Salem	IRESA	Tunisia
Souad	Sessi Dekhil	DGGREE	Tunisia
Awatef	Larbi Messai	DGEQV	Tunisia
Mohamed Ali	Dridi	DGEQV	Tunisia
Khadija	Hamrouni	ONAS	Tunisia
Chokri	Selmi	ANPE	Tunisia
Hatem	Abdelkebir	ANPE	Tunisia
Jamel	Chellouf	DHMPE	Tunisia
Chadia	Abidi	ANCSEP	Tunisia
Mondher	Mansour	ANCSEP	Tunisia
Mohamed	Annabi	INRAT	Tunisia
Yasmine	Mejri	ULT	Tunisia
Hichem	Ben Salem	IRESA	Tunisia
Abderrahman	Ouasli	BPEH	Tunisia
Larbi Mesai	Awatef	DGQVA	Tunisia
Dridi	Mohamed Ali	DGQVA	Tunisia
Dones	Alila	ANPE	Tunisia

Appendix 4: List of Participating Experts

INTERNATIONAL TEAM OF EXPERTS

in alphabetical order

Dr Serena Caucci
United Nations University (UNU-FLORES)
Dresden, Germany

As a researcher at UNU-FLORES Dr Caucci contributes to the scientific work and realisation of multi-stakeholder capacity development projects on topics such as the Safe Use of Wastewater in Agriculture (SUWA), sustainable sludge management options, and environmental risk assessment. Dr Caucci has closely worked with transdisciplinary partners and developed wide international collaborations in the field of environmental risk assessment related to sanitation processes, contaminants of emerging concern, pollution management, and water quality in both agriculture and the environment. Before joining UNU-FLORES, she worked at the Institute of Hydrobiology at Technische Universität Dresden and at the Helmholtz Centre for Environmental Research - UFZ on decentralised wastewater technologies, water sanitation, biodiversity, and antimicrobial resistance in anthropogenic-driven environments worldwide.

Samir Gabsi
Ministry of Agriculture, Water Resources and Fisheries
Nabeul, Tunisia

Gabsi is a Chief Engineer working as the District Manager Exploitation of Irrigated Perimeters at the Regional Commissariat for Agricultural Development of Nabeul. His main activities include the management and evaluation of the exploitation of the PPI and programming as well as monitoring of the distribution of irrigation water. Gabsi also supervises and monitors the GDA. Currently he is working on water resources and agricultural activity in Korba.

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INTERNATIONAL CAPACITY
DEVELOPMENT WORKSHOP

Tiba Haggui

Directorate General of Water Resources

Tunis, Tunisia

Haggui joined the Department for Non-Conventional Water Resources and Artificial Recharge of the Directorate General of Water Resources in 2010. As a Project Manager, she worked on the vulnerability of the Aousja Ghar el Melh aquifer to climate change and pollution (in partnership with UNESCO). She has also been the focal point of the study on the inclusive governance of the Guenniche aquifer (in partnership with FAO). Since 2016 she is responsible for the Sub-Directorate for Artificial Recharge. A Chief Engineer, Haggui holds a Diploma in Hydraulic and Planning Engineer with honours and was granted the presidential award in 2005.

Prof. Hiroshan Hettiarachchi

United Nations University (UNU-FLORES)

Dresden, Germany

Prof. Hettiarachchi heads the Waste Management Unit at UNU-FLORES. His background is in civil engineering and he has conducted research and published extensively in the areas of geotechnical and geoenvironmental engineering and sustainable waste management. His recent work is more focused on sustainable environmental resources management, which has specifically resulted in a number of scientific and capacity development workshops in Asia, Africa, and South America on Safe Use of Wastewater in Agriculture (SUWA), considered as one of the golden examples of the Nexus Approach. He is also an expert in graduate programme development and took the lead in developing the Joint PhD Programme in Integrated Management of Water, Soil and Waste offered by UNU-FLORES in partnership with Technische Universität Dresden. Prior to joining UNU, he was at the Lawrence Technological University in Michigan, USA.

Christian Kjær Jensen

Technical University of Denmark (DTU)

Copenhagen, Denmark

Jensen is an environmental engineer working at the Technical University of Denmark (DTU) in the group of Prof. Stefan Trapp at DTU Environment, Department of Environmental Engineering. His expertise is in modelling the uptake of chemicals in plants, especially through wastewater reuse in agriculture. DTU Environment is one of the largest university departments specialising in water, environmental engineering, and sustainability in Europe. The department is working to develop new environmentally-friendly and sustainable technologies and to disseminate knowledge to policymakers and industries.

Prof. Olfa Mahjoub

National Research Institute for Rural Engineering, Water, and Forestry (INRGREF)
Tunis, Tunisia

Interested in emerging contaminants in water resources and soil, water management and quality, wastewater reuse, and risk assessment and management, Prof. Mahjoub has years of research and teaching experience. As an agricultural engineer she has conducted research investigations in areas that allowed her to work as water quality and reuse specialist. She currently serves at the National Research Institute for Rural Engineering, Water, and Forestry (INRGREF) in Tunisia. Prof. Mahjoub has been a project coordinator and member of various international consortia for research and development partnerships, such as the Tunisian-German cooperation (DAAD), Tunisian-American cooperation (USDA), and African Union Commission among others.

Manfred Matz

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
Tunis, Tunisia

Matz coordinates projects on water resources management practices through better policies, application of existing regulations, and multiple stakeholder agreements. His core expertise is in advisory services on water resources and water utilities management, project planning, and evaluation. Matz collaborates closely with the water ministry, regional administration, and the Observatoire du Sahara et Sahel (OSS) as well as academia and civil society. Previously he worked with the Stockholm International Water Institute as Head of the Internal Water Policy Advisory Service to the Swedish Development Agency (Sida) and for international development companies in Africa. His work contributed to the development of knowledge and capacity development in more than 40 countries worldwide. Matz holds an engineering degree from the Applied University of Bielefeld on water management.

Appendix 5: Impressions from the Workshop

UNITED NATIONS
UNIVERSITY

UNU-FLORES

The United Nations University Institute for Integrated Management of Material Fluxes and of Resources (UNU-FLORES) was established in Dresden, Germany in 2012 with the support of the Federal Ministry of Education and Research (BMBF) and the Ministry for Higher Education, Research and the Arts (SMWK) of the Free State of Saxony, Germany. As part of the United Nations University (UNU), the Institute helps build a bridge between the academic world and the United Nations. UNU encompasses 13 research and training institutes and programmes located in 12 countries around the world. UNU as a whole aims to develop sustainable solutions for pressing global problems of human survival and development.

UNU-FLORES develops strategies to resolve pressing challenges in the area of sustainable use and integrated management of environmental resources such as water, soil, and waste. Focusing on the needs of the UN and its Member States, particularly developing countries and emerging economies, the Institute engages in research, capacity development, advanced teaching and training, as well as dissemination of knowledge. In all activities, UNU-FLORES advances a Nexus Approach to the sustainable management of environmental resources.

Find more information at: **flores.unu.edu**

ADVANCING A NEXUS APPROACH TO THE SUSTAINABLE MANAGEMENT OF ENVIRONMENTAL RESOURCES

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